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Physiological and clinical advantages of median nerve fascicle transfer to the musculocutaneous nerve following brachial plexus root avulsion injury

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Object. Loss of biceps muscle function is a significant disability after brachial plexus root avulsion injuries. Nerve grafting techniques to reestablish anatomical and functional continuity between the spinal cord and the avulsed root have not proven successful. Using nerve transfers for functional restoration of root avulsion injuries appears to be effective and has physiological advantages for reducing regeneration distances. Since the early 1990s, the Oberlin technique of transferring ulnar nerve fascicles to the motor branch of the musculocutaneous nerve has been the preferred operative technique for reinnervation and restoration of biceps muscle function. In the current study the authors examine the efficacy of an alternative technique using median nerve fascicles transferred to the musculocutaneous nerve to reinnervate the biceps muscle.

Methods. Forty consecutive patients with combined C5–6 brachial plexus root avulsions were evaluated pre- and postoperatively according to the British Medical Research Council Motor Grading Scale. Personal interviews concerning quality of life (QOL) after surgery were conducted and scored based on standards set by the World Health Organization. All patients showed some degree of improvement in biceps muscle function. Thirty-six (90%) of the 40 patients regained movement against gravity. The patients had a 77% improvement in overall QOL after the surgery; most notably, 92% of the patients reported their lack of need for medication and 75% a significant lessening of postoperative pain. Redirection of part of the healthy median nerve resulted in no measurable functional deficits, and only 28 patients reported minor sensory disturbances in the first web space for an average of 3 months after surgery.

Conclusions. Median nerve fascicle transfer resulted in a significant improvement in biceps muscle function with an acceptable level of morbidity and should be considered an effective, and in many cases preferable, alternative to ulnar nerve fascicle transfer.

KEY WORDS • brachial plexus avulsion • nerve injury • peripheral nerve • median nerve • nerve transfer

DENERVATION of the biceps muscle is an inevitable consequence of severe upper root or trunk injuries of the brachial plexus. These high nerve injuries result in challenging reconstructive issues for the surgeon. The relatively slow rate of peripheral nerve regeneration and the inexorable pace of motor endplate loss create physiological limitations to restoring extremity function using high nerve anatomical reconstruction.[3] Avulsion injuries can be addressed with nerve transfers in the hopes of restoring biceps muscle function. Using the nerve transfer technique the surgeon attempts to avoid the distance and time constraints on anatomical reconstruction by transferring distal donor motor or sensory axons to injured nerves close to the affected end organs. In the current patient series, median nerve fascicles were transferred to the motor branch of the musculocutaneous nerve. This procedure is a modification of the traditional technique of Oberlin,[9] which uses fascicles from the ulnar nerve to reinnervate the biceps muscle.

Clinical Material and Methods

Patient Population

This study consisted of 40 consecutive patients who had suffered C5–6 brachial plexus root avulsion injuries within a 5-year period. The median nerve was intact in all patients despite these injuries. Twenty-three of the patients had left-sided injuries, and 17 had right-sided injuries. Twenty-four patients were men, and the average age of all patients was 24.2 years (range 0.83–54 years). The British MRC Grading Scale was used to standardize the measurement of biceps muscle strength by assigning a numeric value from 0 (total paralysis) to 5 (normal strength) to characterize muscle movement.

The same experienced brachial plexus surgeon (R.K.N.) evaluated and performed surgery in all patients. Initial examinations by the surgeon were conducted an average of

Abbreviations used in this paper: MRC = Medical Research Council; QOL = quality of life.

5 months (range 2–9 months) from the date of injury, and surgery followed within 2 days of this evaluation. At the time of the preoperative evaluation a diagnosis of biceps muscle MRC Grade 0 motor strength was made in 35 of the 40 patients. In all patients preoperative somatosensory evoked potential and electromyography test results were consistent with brachial plexus root avulsions. These findings were further confirmed with intraoperative nerve testing, which indicated combined denervation of both the C-5 and C-6 nerve roots. The majority of these patients were unable to undergo long-term postoperative electrophysiological testing to further confirm recovery because they resided out of state. Patients received both preoperative and postoperative QOL evaluations, however, through face-to-face and telephone interviews with the same investigator, who was not the operating surgeon. The interview was given to evaluate aspects of surgical recovery using 11 facets within four domains of the World Health Organization QOL questionnaire.[15] The four domains of the questionnaire were physical health, psychological health, level of independence, and social relations. The 11 facets included assessment of energy and fatigue, pain, sleep, body image and appearance, self-esteem, mobility, ability to perform daily living activities, dependence on medications, work capacity, personal relationships and social support, and overall QOL after the procedure. Responses were scored from 1 to 5 according to the scale incorporated in the field trial questionnaire, in which a score of 1 represented a negative response; 3, indifference or no change; and 5, a positive response.

The operating surgeon obtained strength measurements in all patients postoperatively. All patients completed the same QOL questionnaire a minimum of 1 year after surgery.

Surgical Technique

At the operation, the arm and neck of the patient were prepared and draped in the usual sterile fashion. The injured brachial plexus was exposed in the supraclavicular fossa, explored, and tested. Root avulsion injury was confirmed in all cases by direct physical examination and by intraoperative somatosensory evoked potential and electromyography testing.

The medial arm was exposed by creating an incision along the interval between the biceps and triceps muscles, in the upper and middle third of the arm. Retractors separated the biceps and triceps muscles, revealing the neurovascular structures of the arm (Fig. 1). The median nerve was noted, and the musculocutaneous nerve was found immediately deep and lateral to the median nerve, usually within the substance of the biceps muscle adjacent to a tendinous fascial band. The biceps motor branch of the musculocutaneous nerve was recognized as it branched laterally from the main trunk of the musculocutaneous nerve at the midpoint of the biceps muscle. The musculocutaneous nerve branch to the brachialis muscle was identified as it branched to the lateral aspect of that muscle distal to the origin of the biceps motor branch.

Fascicles of the median nerve to be used for donation were selected through intraneural neurolysis and electrical stimulation of separated fascicles adjacent to the musculocutaneous nerve, using a nerve stimulator (Vari-Stim; Medtronic Xomed, Inc., Jacksonville, FL) at 0.5 mAmp. Internal neurolysis was conducted using a hemostat and microsurgical instruments under high magnification between 4.0 and 8.0. Generally, the superomedial fibers of the median nerve tended to provide forearm pronation on stimulation; therefore, these fibers were chosen for the transfer. Two fascicle groups were chosen, one each for the biceps motor branch and the brachialis motor branch. The selected fibers were transected distally, and then transposed to the musculocutaneous nerve. Approximately 20% of the fascicles of the median nerve were used in this transfer.

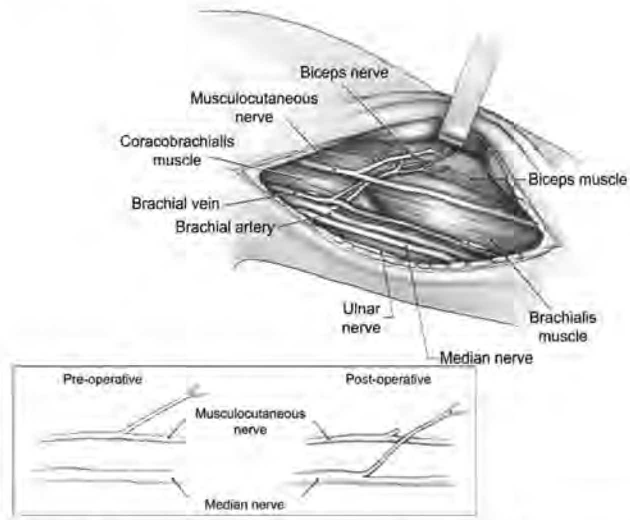

FIG. 1. Illustration showing exposure of neurovascular structures of the medial left arm. *Inset:* Illustration of the transfer of a medial nerve fascicle to the motor branch of the musculocutaneous nerve.

After a varied amount of intraneural neurolysis along the course of the musculocutaneous nerve, the motor branches to the biceps and brachialis muscles were identified and separated. The lateral antebrachial cutaneous nerve component of the musculocutaneous nerve was carefully excluded to prevent unintentional inclusion as a donor for the median nerve transfer.

Microscopic guidance was used to join the donor and recipient fascicles by using interrupted epineurial 10-0 sutures placed in a circumferential fashion. Before closure of the incision, the arm of each patient was moved through a full range of motion to confirm that excessive tension would not be present during postoperative movement.

All patients were prescribed a postoperative regimen of physical and/or occupational therapy, including regular galvanic electrical stimulation of the denervated biceps muscle. This regimen of electrical stimulation was prescribed in accordance with standard peripheral nerve surgery practices that are supported by data.

Results

This study included 40 consecutive patients whose documented C5–6 brachial plexus root avulsion injuries resulted in a loss of biceps muscle function (Table 1). Thirty-six (90%) of the 40 nerve fascicle transfers resulted in significant recovery of biceps muscle movement against gravity with the ability to lift added weight, or MRC Grade 4. Of the four remaining patients, two reached a maximum recov-

TABLE 1

*Preoperative and postoperative MRC scoring of biceps muscle function in 40 patients with median nerve fascicle transfer to the motor branch of the musculocutaneous nerve**

Case No.	Age (yrs)	MRC Grade: Preop Mallet Biceps Strength	MRC Grade: Postop Mallet Biceps Strength	Time Elapsed Before Op (mos)
1	31	0	4	4
2	20	0	4	6
3	22	0	3	9
4	25	0	4	4
5	0.83	1	4	7
6	30	0	4	3
7	24	0	4	6
8	19	0	4	6
9	14	0	4	3
10	22	0	4	5
11	24	0	4	4
12	31	0	4	7
13	20	1	4	5
14	22	0	4	5
15	25	0	4	4
16	19	0	4	2
17	54	0	4	4
18	22	1	4	4
19	25	0	4	3
20	21	0	3	8
21	18	0	4	5
22	20	0	4	6
23	25	0	4	9
24	22	0	4	4
25	22	0	2	8
26	19	0	4	5
27	40	0	4	6
28	23	1	4	5
29	20	0	4	4
30	28	0	4	5
31	32	0	4	9
32	25	1	4	4
33	37	0	4	4
34	29	0	2	9
35	33	0	4	2
36	24	0	4	8
37	17	0	4	5
38	26	0	4	5
39	24	0	4	5
40	21	0	4	3

* For all patients, the mode of trauma was a motor vehicle accident.

ery of MRC Grade 2 with return of movement at the joint but no ability to overcome gravity, and the other two patients achieved biceps muscle recovery categorized as MRC Grade 3, movement against gravity without added resistance. The average overall improvement in biceps muscle function in all patients was an increase of four MRC grades. A concomitant overall improvement of 3.5 MRC grades was observed in deltoid muscle function (Table 2).

Maximum postoperative functional recovery in this type of surgery is reached before 2 years, due to the loss of an adult muscle's ability to reinnervate after 15 to 18 months of paralysis. It took an average of 9.7 months (range 1–24 months) for the 36 patients in this study to reach maximum recovery (MRC Grade 4). These patients began to notice the first recovery of biceps muscle movement and improvement after an average of 4 months (range 1–12 months) after surgery.

TABLE 2

*Preoperative and postoperative MRC scoring of 40 patients with median nerve fascicle transfer to the motor branch of the musculocutaneous nerve**

Variable	Median MRC Functional Grade: Preop	Median MRC Functional Grade: Postop
deltoid muscle	0.0	3.5
biceps muscle	0.0	4.0
global score (sum)	0.0	7.5

* Preoperative–postoperative comparisons in which the Wilcoxon signed-rank test was used were statistically significant ($p < 0.001$).

A decline in biceps muscle return was evident after surgical delays longer than 7 months (Fig. 2). The four patients with the least return of muscle function averaged 8.5 months between injury and surgery, compared with an average of 4.8 months in those with an MRC Grade 4 recovery.

Rerouting a portion of the healthy median nerve did not appear to result in a loss of function as long as fascicle selection was performed meticulously and with careful attention to choosing predominantly pronator fascicle groups. This meticulousness also improved forearm balance by more closely matching already weak supination strength due to biceps muscle loss. In 28 cases, patients reported paresthesia in the first web space, which was short-lived, lasting an average of 3 months after surgery. No infection or other complication was noted, and all patients had an uneventful hospital stay and recovery.

Responses to the World Health Organization questionnaire were positive. The average increase in scores for all 11 facets was 3.88, or a "good amount" of improvement. Statistical analysis performed using the Wilcoxon signed-rank test indicated significance with all probability values less than 0.001. The patients had a 77% improvement in overall QOL after the surgery. The majority of patients (92%) reported a lack of dependence on medications, and 75% a significant lessening of postoperative pain. Overall the least amount of satisfaction (3.24 score) in the patients after surgery was the acceptance of bodily appearance. Although biceps muscle function returned in most patients, muscle atrophy was still present to some degree and caused asymmetry with the unaffected limb. Only two patients continued to have complaints of pain. Four of the 40 patients were unsatisfied with their capacity for work and ability to perform daily activities.

Discussion

Nerve transfer to peripheral nerves injured at proximal levels seeks to maximize functional outcome by decreasing the distance and time elements of neural regeneration, and by increasing specificity of donor inflow. Nerve transfers are thus attempted to convert high nerve injuries into low nerve injuries.[4,6,10]

Advantages of Using the Nerve Transfer Technique

Preservation of Muscle Structure. After 15 to 18 months of denervation, skeletal muscle becomes refractory to reinnervation.[11] This time constraint is the primary consideration in designing motor nerve transfers. Donor nerves are transected as distally as possible, then coapted to recipient nerves as closely as possible to the denervated muscle. This reduces the distance, and therefore the time to reinnervation.

Avoidance of Nerve Grafting. Most donor nerves are selected because of their proximity to the denervated muscle. The length of appropriately chosen donor nerves almost always precludes the need for interpositional nerve grafting, enhancing efficacy of nerve regeneration.[2] Grafts, if required, are short. Direct nerve transfer includes only one microsurgical interface compared with two for nerve grafting, which introduces an extra repair site interface that regenerating units need to cross.[5] Direct nerve transfer theoretically decreases misdirection and dropout of regenerating units proceeding distally.

Dedicated Function. Mixing of sensory and motor axons at proximal levels is heterogenous but organizes distally into homogenous sensory and motor fascicles and branches.[12,14] Nerve reconstruction at plexal levels, therefore, carries the risk of functional mismatching, whereas distal nerve transfers provide relatively pure motor and sensory sources. The synergism of action between donor and recipient nerves is preferable, but not necessary.

When determining whether a nerve transfer procedure would be advantageous to a patient the "Rule of 18" should be considered. This concept is based on measured rates of nerve regeneration (1 inch/month) and irreversible muscle atrophy (18 months in adults). The number of inches from the site of nerve injury to the supplied muscle added to the number of months the muscle has been denervated should be less than the number 18 for primary nerve reconstruction to be attempted successfully.[7]

Oberlin[9] was the first to use fascicles of the ulnar nerve joined to the motor branch of the musculocutaneous nerve to reinnervate the biceps muscle. His technique has become a common procedure to regain elbow flexion through the use of about 15% of the fascicles of the ulnar nerve.[1,8,9,13] The main goal of this study was to determine the efficacy of a modification to the Oberlin technique, using the median nerve as the donor source of motor fascicles. The median nerve is technically easier to work with because of its larger diameter. As a corollary benefit, a physically larger mass of the median nerve is available for transfer, so that restoration of both biceps and brachialis motor function for elbow flexion is possible. In addition, its proximity to the musculocutaneous nerve makes reconstruction easier.

Conversely, the ulnar nerve, because of its relatively remote location and smaller diameter, requires more extensive intraneural dissection to obtain sufficient length of the donor fascicle group to reach the musculocutaneous nerve, and potential injury to the intrinsic hand muscle component of the ulnar nerve is a significant disadvantage. It is also difficult to select sufficient mass of the ulnar nerve as donor fascicles to account for both the biceps and the brachialis motor branches of the musculocutaneous nerves. The high success rate with our median nerve transfer patient series is probably due in part to reconstruction of both biceps and brachialis function. As previously mentioned, the ability to rebalance forearm rotation movements through use of pronator fibers of the median nerve enhances the ability to provide overall functional improvement of the injured extremity, which cannot be said of ulnar nerve transfer. The

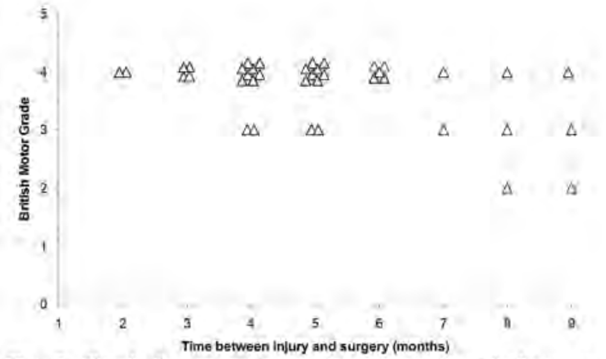

FIG. 2. Graph demonstrating an inverse relationship between a longer period of time elapsed from injury to surgical nerve transfer (x axis) and an MRC grade improvement (y axis).

distance component for the Rule of 18 can be significantly reduced by using a few fascicles of the adjacent median nerve as a nerve transfer to provide motor fibers to the biceps motor branch of the musculocutaneous nerve, giving the procedure a significantly improved chance of success.[3] Even relatively late reconstruction of high nerve injuries therefore has the potential for successful functional reconstruction.

Conclusions

Injury to the brachial plexus commonly results in complete or partial limb paralysis, leaving patients with a painful disability. For cases of functional deficit in elbow flexion, median nerve transfer to the musculocutaneous nerve has proven to be an effective treatment for the functional loss. The net effect of this technique is to convert a high nerve injury to a low nerve injury, by substituting functional for anatomical reconstruction. A slight deficit may always remain; however, with increasingly advanced microsurgical techniques, most patients can expect excellent recovery of functionality. The overall effectiveness and low morbidity of median nerve transfer for elbow flexion restoration in these situations suggests that it is the treatment of choice, with anatomical and functional advantages over ulnar nerve transfer.

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